Human Factors Issues in Advanced Moving-map Systems

Dr John W. Ruffner

(*DCS Corporation*)

Maura C. Lohrenz and Michael E. Trenchard

(*Naval Research Laboratory*, *Stennis Space Centre*)

Vector-based maps are an advanced capability of digital moving-map systems that are easily customised and can be powerful aids to aircrew information processing and decision-making. However, they may place excessive demands on an aircrew's information processing requirements, cause an increase in workload, and degrade situational awareness if the user interface is not designed properly. There is little information available about the human factors and situational awareness issues relevant to vector-based maps. In this paper, we summarise relevant research on human factors and situational awareness aspects of using vector-based maps, identify key issues, and recommend directions for future research.

KEY WORDS

1. Maps/Charts. 2. Human Factors. 3. Situational Awareness.

1. INTRODUCTION. Aircraft digital moving-map systems are designed to provide useful information for navigation and tactical tasks and to allow the aircrew to focus their attention on performing these tasks with a minimum amount of head-down time. When properly designed, digital moving-maps should display information more efficiently than paper maps such that aircrew can obtain all the information required to assess a situation and accomplish a task with a quick glance. Digital moving-map systems should also provide the aircrew with the ability to access and control the displayed information selectively (Rogers and Spiker, 1988; Unger and Schopper, 1995).

Vector-based maps, which are an advanced capability of digital moving-map systems, differ from conventional raster-scanned maps in that they are rendered from individually stored objects, including points with associated symbols (e.g., airports), linear features (e.g., roads), and areas (e.g., shaded cities) (Willis and Goodson, 1997). These point, linear, and area features are often arranged in multiple data layers (or libraries) organised and interrelated via a relational or object-oriented database structure. The features are stored using identification codes in related groups (classes) and displayed via bitmapped symbology. They are selectable by major or minor classes so permitting a display to be customised. For these reasons, vector-based maps and map overlays have the potential to be powerful aids to aircrew information processing and decision-making. However, they may place excessive demands on an aircrew's information processing requirements, increase workload, and degrade situational awareness if the user interface is not designed properly. Unfortunately,

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there is little information available about the human factors and situational awareness issues relevant to vector-based maps; these factors and issues need to be identified and resolved for successful implementation of future moving-map displays.

Vector-based maps are of particular interest to the Naval aviation community because they are being considered as a top priority enhancement to the Tactical Aircraft Moving-Map Capability (TAMMAC) program. The TAMMAC system consists of a Digital Map Computer (DMC), an Advanced Memory Unit (AMU) for loading of map and mission planning data and logging of maintenance data, and a high speed interface bus. TAMMAC will be the standard cockpit digital moving-map system for the US Navy and will be used by a variety of aircraft with different operational needs. TAMMAC can be tailored to meet each aircraft's operational requirements by selecting from several capabilities. A major design goal of the TAMMAC program is to enhance situational awareness (SA) and aircrew mission effectiveness without further burdening pilot workload (Lohrenz et al., 1997a; Ruffner and Trenchard 1997, 1998). Specific baseline and growth features of the TAMMAC DMC are identified in Section 4.

2. SITUATIONAL AWARENESS. Situational awareness (SA) is usually considered to be important for mission effectiveness and safety across a variety of human performance domains. Furthermore, it is commonly believed that good performance is linked to good SA (Endsley, 1995). Wickens (1995, 1996) defined SA as 'the continuous extraction of information about a system or environment, the integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception, anticipation, attention or response.' This closely parallels the definition proposed by Endsley (1995), in which SA is defined as the *perception* of the critical elements of an environment in time and space (Level 1), the *comprehension* of their meaning, particularly when integrated in relation to the aircrew's goals (Level 2), and the *projection* of what will happen with the system in the near future (Level 3). It is widely believed that higher levels of SA allow pilots to function in a more timely and effective manner.

SA can be global or local (Endsley, 1997a). In the context of digital moving-map systems, global SA information needs would include one's location within a broad geographical area, navigation information such as the relative location of important features, the current location and direction of movement of friendly and enemy units, and current commands and directions. Local SA needs would include the location of a desired target in the immediate environment, the identity (friend, foe, or neutral) of an entity under current targeting, terrain and object location (as needed for manoeuvring), and cueing of the presence and movement of threats in the immediate environment. Both global and local SA are critical for effective aircrew functioning in a given environment. Furthermore, several investigators have suggested that SA is multi-dimensional. For example, Endsley (1997a) proposed that several classes of elements were required for SA: geographical, spatial/temporal, system, environmental, and tactical. Wickens (1995) suggested that overall SA should be broken down into hazard awareness, system awareness, and task awareness. Coury and Wilson (1994) proposed that there were five SA aspects: spatial, identity, temporal, responsibility, and expectancy. Some of these classes of SA elements (e.g.,

geographical, tactical) will most likely be more relevant to enhancing SA with vector-based maps than others (e.g., system, environmental).

3. RELEVANT RESEARCH. In a previous paper (Ruffner and Trenchard, 1998), the results of selected studies conducted to identify the functional requirements and desirable features and capabilities for digital moving-map systems were summarised. In this section of the present paper, the key points of three of these studies, which are most relevant to enhancing SA with vector-based maps, are highlighted.

3.1. *US Army Digital Map Functional Requirements Analysis.* A comprehensive programme to identify the functional requirements of ground-based mission planning systems and airborne digital map systems for US Army aviators was conducted by Rogers and his colleagues (Rogers, 1983; Rogers and Cross, 1979; Rogers and Spiker, 1988; Rogers, Gutmann, and Ralstin, 1982). This programme drew on the findings of investigations on aircraft navigational requirements, map usage, and the effects of various display variables on the perception of topographic features and symbology. Rogers (1985) identified four potential advantages of a computer-generated topographic display system that are relevant to vector-based maps:

(i) *It provides the potential for comprehensive and rapid response and cartographic support*. As compared to the long lead-time required for conventional or photo-based maps, it is possible to obtain the data required to support computer-generated display systems within hours as compared to weeks or months.

(ii) *It allows the aviator to control the content of the displayed information*. Aviators can select the information that is optimal for the task and situation at hand, can control the classes of information that are displayed (e.g., vegetation, hydrography), and can select the specific features of a given class of information (e.g., deciduous trees, perennial streams). In addition, aviators can alter the scale and contour interval to tailor the map to changing requirements.

(iii) *It provides a powerful computational capability*. The increased computational capability of a digital map system provides the basis for several improvements that can increase the interpretability of the map features. Examples of these are:
   (a) using shaded elevation bands to indicate areas where the surrounding terrain is equal to, higher or lower than the altitude at which the aircraft is currently flying;
   (b) presenting a shaded relief map enhanced by contour lines;
   (c) displaying the areas masked from visual or radar observation given known or likely enemy positions; and
   (d) constructing perspective views to familiarise the aviator with the terrain as it will be seen during flight.

(iv) *It provides an increased degree of interactivity*. An aviator can enter information such as map annotations, coordinates of objectives, planned routes, etc., which can be selected as needed. The 'intelligent' nature of the system permits the aviator to interrogate it to determine characteristics of the portrayed features, such as tree height and threat missile lethality. Thus, the interactive nature of

> the system can help remove some of the natural limits to the aviator's decision-making capabilities and permit him or her to solve complex problems rapidly.

Based on the findings of these studies, Rogers (1985) identified several desirable functions or capabilities for a computer-generated digital map that are relevant to vector-based maps. These include:

- The ability to present different map scales (e.g., 1:50,000, 1:250,000);
- The ability to show different map areas (e.g., near, remote);
- The ability to present different types of terrain information (e.g., contour lines, slope shading);
- The ability to present different map orientations (e.g., north-up, track-up);
- The ability to show areas of masking and inter-visibility (e.g., clear line-of-sight);
- The ability to select and depict a wide variety of features (e.g., topographic, tactical); and
- The ability to depict elements of a flight plan with annotations (e.g., flight path, waypoints).

3.2. *Human Factors Analysis of AH-1W Moving-map Requirements.* Ruffner and Puccetti (1996) conducted a survey of previous digital moving-map system research and of existing or developmental digital map systems to identify desirable capabilities for the US Marine Corps AH-1W attack helicopter. The work of Rogers and his colleagues, described previously, was summarised in their report. One of the programmes reviewed by Ruffner and Puccetti, the RAH-66 *Comanche* digital map development programme, represents a 'model' development effort from a human factors perspective in which SA was a critical design driver (Hamilton, 1993; Hamilton and Metzler, 1992). The *Comanche* digital map was designed using a *pilot-centred approach*. This approach was characterised by a design philosophy in which data for SA and decision making were brought to a centralised display location in a manner that is quickly interpreted relative to the mission, phase, or task being performed. In addition, the map information was provided in a format compatible with the information demands of the crew and organised for the pilot's most direct comprehension and application. The *Comanche* digital map was designed to serve as a mission information database and crew-aircraft interface as well as a primary navigation aid.

Based on their findings, Ruffner and Puccetti (1996) recommended several capabilities that should be implemented in the AH-1W digital map that had the potential for enhancing SA. These included: allowing the pilot to select the contour line interval appropriate for the mission phase, showing areas of masking and inter-visibility to depict the likelihood of being observed or detected, allowing north-up, track-up, and heading-up map orientations, allowing centred or offset location of ownship, and allowing slewing of the map to another selected area.

3.3. *US Navy Human Factors Digital Map Requirements Study.* The Naval Research Laboratory (NRL) conducted a study of US Navy and Marine Corps pilot preferences for map features and capabilities as a basis for identifying TAMMAC digital moving-map system requirements. Researchers conducted one-on-one aircrew evaluations of digital maps and display parameters for military cockpits. The researchers guided experienced aircrew through task-structured scenarios, presented a variety of tactical and topographic features for evaluation, and surveyed

participants' preferences based on their platform applications. Representative scenarios were presented illustrating candidate map capabilities such as: map positioning (e.g., north-up, track-up, centred-offset); zooming (e.g., zoom in/out, continuous versus discrete zoom); presentation of terrain elevation data (e.g., contour lines, plan versus perspective views); map overlay data (e.g., threat location and range); and vector map displays. A detailed account of the background, methodology, and findings from this study can be found in Lohrenz, et al. (1997a) and Lohrenz, et al. (1997b). Selected study findings relevant to SA with vector-based maps are provided in this section.

3.3.1. *Map Positioning*. Most pilots preferred track-up orientation over a north-up for improved SA and preferred a centred aircraft display while the map was in north-up orientation. The pilots considered the north-up orientation to be disorienting in flight but good for waypoint insertion.

3.3.2. *Zooming*. The pilots preferred zooming up to the scale of the next chart series, then switching series to maintain SA. They judged continuous zoom as desirable to maintain SA in a controlled, predictable, and fast manner. The pilots judged that one-step zoom made it hard to keep track of SA but that zoom-out supported maintaining big-picture awareness.

3.3.3. *Terrain Elevation Data*. There was no strong preference for a two-dimensional (2-D) versus a three-dimensional (3-D) view, with the judged effectiveness varying with terrain elevation display mode (e.g., terrain and chart data, terrain and imagery). The pilots considered sun angle shading to be a good SA builder for flying in terrain, with a fixed sun angle preferred over a variable sun angle for maintaining SA. Furthermore, contour lines were preferred more by helicopter pilots than by fixed-wing tactical pilots for maintaining SA.

3.3.4. *Overlay Data*. The pilots judged the height above terrain (HAT) and clear line-of-sight (CLOS) capabilities to be extremely valuable for terrain avoidance and recommended HAT as a user-selectable feature. The pilots rated threat rings as very useful for displaying inter-visibility, more so when the threat rings were overlaid on imagery than on chart data. The pilots preferred translucent overlays of shaded threat rings to a 'spokes' representation. The threat rings with translucent shading made it much easier to see the underlying map information than did the spokes, which obliterated some of the base map.

3.3.5. *Vector Maps*. The pilots favoured the capability of vector maps for keeping text upright in track-up orientation and selectively de-cluttering the display. Pilots thought the vector map capability provided enhanced flexibility and display optimisation and considered it good for building and sustaining SA. On the negative side, the pilots were concerned that vector maps might add complexity and increase workload. There were also concerns that vector maps may require additional pilot training. From a technical perspective, vector maps are likely to require additional processing and capability and some level of automated cartography.

Overall, the findings suggested that pilots favoured using a more realistic base-map for SA, but overlaying the base-map with high contrast, mission-specific features. In addition, the pilots expressed a strong preference for keeping the map as simple as possible for more rapid assimilation of information during flight and for developing SA. Finally, the pilots recommended putting more options in the mission planner and keeping in-flight options to a minimum for the greatest SA benefit while minimising in-flight workload.

4. TAMMAC–DIGITAL MAP COMPUTER CAPABILITIES. Based on the findings of the studies discussed in Section 3, as well as inputs from aviators from the different aircraft platforms, several capabilities or features (e.g., map overlay symbology) are being incorporated as baseline requirements in the TAMMAC Digital Map Computer (DMC). Other capabilities (e.g., vector map displays) are considered to be growth capabilities that will be implemented at a later date. In this section, we identify key TAMMAC DMC baseline and growth capabilities to provide the reader with a basis for the discussion of SA guidelines and human factor research and design issues relevant to vector map displays in Sections 5 and 6. The reader is referred to Williams (1998) for a detailed description and pictorial representation of the TAMMAC DMC features. Table 1 provides examples of TAMMAC DMC baseline features and Table 2 provides examples of growth features. Figure 1 illustrates how the Dynamic Display Overlay baseline feature might be implemented using elevation colour-banding and threat rings. Figure 2 illustrates how the de-cluttering feature might be implemented. TAMMAC will also be able to incorporate emerging databases from the National Imagery and Mapping Agency, (NIMA) such as the Vector Vertical Obstruction Database (VVOD).

Table 1. Examples of TAMMAC DMC Baseline Features.

- Multiple Display Modes (chart, terrain elevation, imagery, data frame)
- Multiple Display Scales (1:12.5 K to 1:5 M, selectable)
- Selectable Map Orientation/Reference (north-up, track-up, heading up)
- Overlay Symbology (e.g., ownship, waypoints)
- Dynamic Display Overlays (e.g., preplanned/pop-up threats, elevation banding)
- Zooming Capability (e.g., zoom in, zoom out)
- Contour Line Intervals (1ft to 10,000ft, selectable)
- Selectable Trend Dots (indicating aircraft position in 10, 20, and 30 seconds)

Table 2. Examples of TAMMAC DMC Growth Features.

- De-clutter capable Vector Map
- Predictive Terrain Awareness Warning System (TAWS)
- 3-D Perspective View
- Dynamic Threat Rings
- Picture-in Picture Inset Window
- In-flight Mission Re-planning
- Display of Map Feature Foundation Data
- Real-time Imagery in the Cockpit
- High Resolution Digital Video

5. SITUATIONAL-AWARENESS DESIGN GUIDELINES. Endsley (1997b) has suggested several general design guidelines for creating cockpit display interfaces that enhance SA. For example, Endsley recommends that displays should:

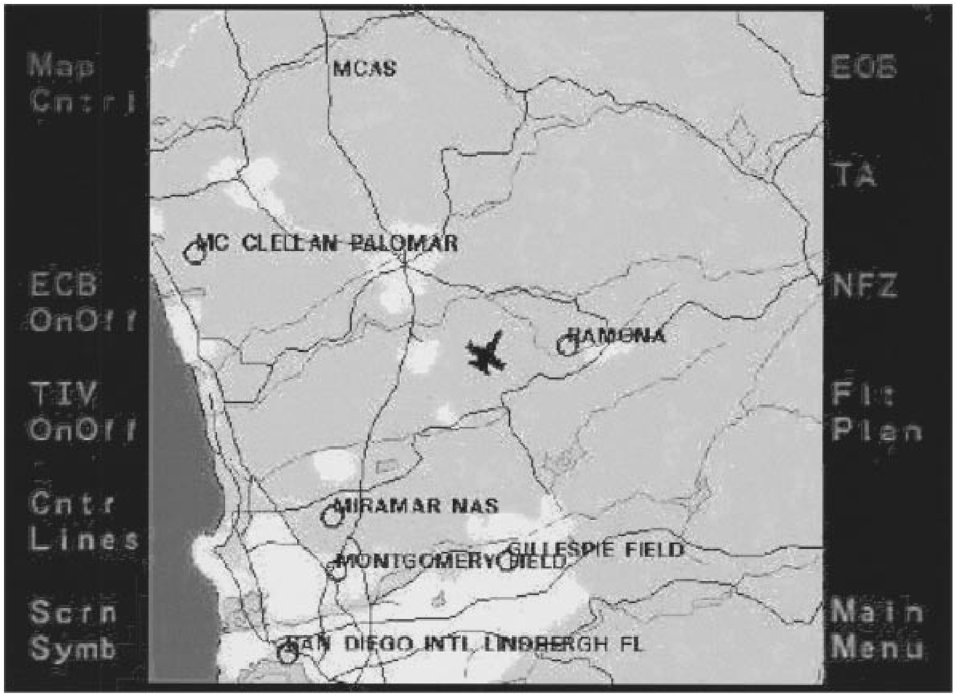

Figure 1. Example of a TAMMAC DMC baseline feature: Dynamic Display Overlay.

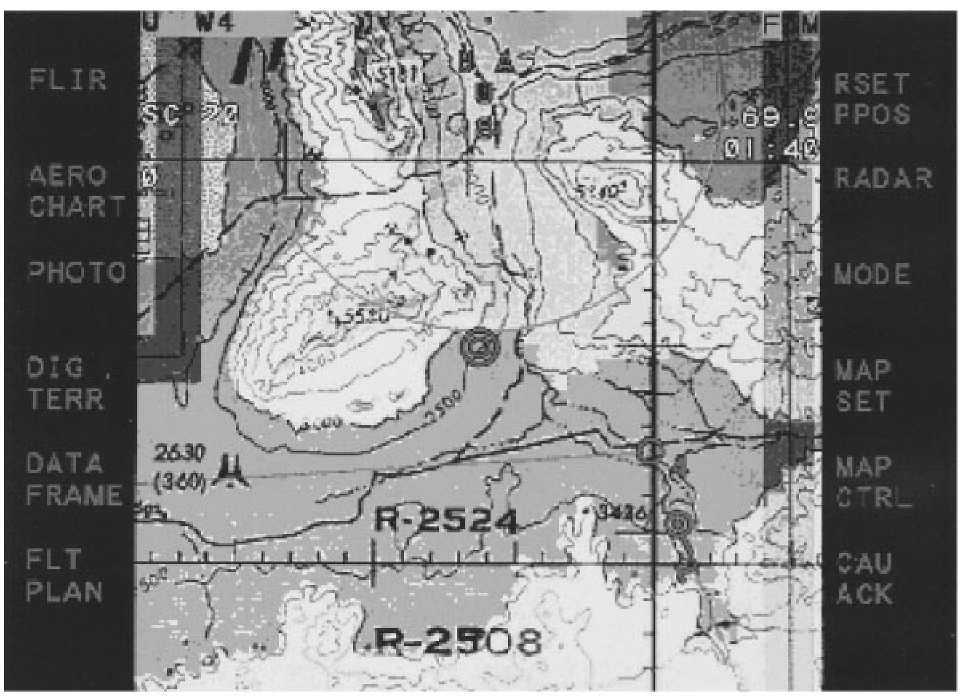

Figure 2. Example of a TAMMAC DMC growth feature: De-clutter capable Vector Map.

(i) provide information processed and integrated for SA Level 2 and 3 needs,
(ii) provide global SA along with goal-relevant detailed information,
(iii) present information in terms of the operator's major goals,
(iv) make critical cues used for activating mental models salient,
(v) filter extraneous information not related to SA needs and reduce data, and
(vi) provide support for projecting future events and system status.

These guidelines provide useful information for enhancing SA for cockpit display systems in general. However, they need to be tailored and selectively applied to the application of vector map displays. For example, the guidelines should provide recommendations for colour and shape symbology coding to depict threat information in a dynamic overlay display to enhance the comprehension of threat status (SA Level 2) and projected ownship vulnerability (SA Level 3). As another example, the guidelines should recommend how data in vector map displays should be selectively added and de-cluttered to build local and global situational awareness.

6. HUMAN FACTORS RESEARCH AND DESIGN ISSUES.

There are several human factors research and design issues that need to be addressed to improve the contribution of vector maps to mission effectiveness and enhancing SA. These include:

(i) What are the individual navigation and tactical tasks that require the development and maintenance of a high level of SA? Which of these tasks are best supported by vector map displays?
(ii) What are the global and local SA information needs of these tasks? How can the capabilities offered by vector map displays be best used to support the pilot's global and local SA information needs?
(iii) What is the most appropriate way to measure workload and SA for tasks that are best supported by vector map displays?
(iv) How can we apply or adapt general SA guidelines to ensure the effective and productive use of vector map display capabilities?
(v) What classes (e.g., geographical, tactical) of SA elements are most important for enhancing SA with vector map displays?

7. CONCLUSIONS AND RECOMMENDATIONS.

Vector maps have the potential for achieving the goal of enhancing situational awareness and aircrew mission effectiveness in real-time displays. The extent to which this potential can be realised without further burdening pilot workload will depend largely on the successful application of research findings from previous digital moving-map systems programmes and careful tailoring of general SA-oriented design guidelines. Vector maps provide a great deal of flexibility to aircrew for selecting map features in support of their specific aircraft mission. Care must be exercised that this flexibility does not become a contributor to overall aircrew workload. Accordingly, more specific guidelines need to be developed and validated for using vector maps in real-time environments to enhance SA. Furthermore, there is a need for a better understanding of the human factors and SA issues affecting the use of vector maps.

The TAMMAC baseline and growth requirements and capabilities were based on user preferences from demonstrations of candidate moving-map capabilities (e.g., Lohrenz et al., 1997a; Lohrenz et al., 1997b). However, there is evidence that preference and performance are not always consistent (Bailey, 1993; Nielsen and

Levy, 1994; Wickens and Andre, 1994). User preference data are an important source of information to guide the design and selection of digital moving-map system features and capabilities. However, preference data should be validated using part-task or full-task simulation scenarios with realistic task loads and appropriate performance measures that are sensitive to the critical system parameters of digital moving-maps (Ruffner and Trenchard, 1998). Specifically, vector map capabilities should be evaluated in user-performance simulations. The results of these simulations can be used to optimise vector map capabilities to enhance SA and increase aircrew effectiveness while decreasing or at least minimising the impact on pilot workload.

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